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Petrographic texture of sediments vis-à-vis aquifer characteristics from WGAMG′0 watershed, Chandrapur district, Maharashtra, India

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The present study deciphers the interrelationship between petrography and texture of sediments with aquifer characteristics. Sandstones representing the aquifers around Minjhari–Murpar village (lat. 20°34′05″N: long. 79°18′05″E), Chimur Tahsil, Chandrapur district, Maharashtra, India corresponding to the watershed WGAMG′ have been selected for the study. These sandstones are grouped as arenites and wackes to unravel the aquifer distinctiveness. The values of transmissivity from 102.28 to 450.42 m^2/day, and for wackes from 58 to 165.59 m^2/day. The values of specific yield (storativity) for arenites range from 20% to 35% and for wackes from 10% to 17%. The computed values of transmissivity as well as specific yield are attributed to the petrographic texture of the rocks. It is propounded that the percentage of detrital grains and matrix is the prime factor that governs the characteristic of aquifers. In addition, it is also found that the sorting of rocks also influences the aquifer performance. The high values of transmissivity and specific yield in arenite aquifer are accountable for higher percentage of detrital grains, lesser amount of matrix and moderate sorting of the grains. Conversely, the lower percentage of detrital grains, higher amount of matrix and poor sorting of the grains are responsible for low values of transmissivity and specific yield in the wacke aquifer.

Keywords: Aquifer characteristics, petrography, texture of sediments, watershed.

IT is now an established fact that the inherent properties of aquifers govern the occurrence and movement of groundwater. These inherent properties in hard-rock aquifers encompass the presence of primary and secondary interconnected conduits and post-emplacement/depositional physical activities like weathering, fracturing, jointing, etc. Extensive work has been carried out on the relationship between occurrence and movement of groundwater, and the above-mentioned inherent hard-rock aquifer properties[1–4]. In sedimentary rocks, the occurrence and movement of groundwater is primarily governed by the grain-to-grain relationship[5–9]. The sedimentological properties govern the movement of groundwater and such well-penetrating aquifers have good yielding capacities[10]. The individual particles of the geological formation are

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not entirely spherical and thus during their deposition by the geological agency[11]. Thus, these particles tend to settle down on their flat sides. Consequently, groundwater movement in the horizontal direction is greater than that in the vertical direction, causing anisotropy. The sedimentary aquifers in the area were analysed for sedimentological characteristics. The aquifers in which specific yield, transmissivity, porosity, etc. showed larger values were recommended for the site development of groundwater abstraction. Such sites are also suitable for recharge[12–16].

The sandstones representing aquifers disposed in watershed WGAMG′0, around Minjhari–Murpar village (lat. 20°34′05″N, long. 79°18′05″E), Chimur Tahsil, Chandrapur district, Maharashtra, Central India were selected for the present study (Figure 1). This watershed represents 5.77% stage of development with rising pre- and post-monsoon water-table trend. Based on these facts, the watershed has been categorized as ‘safe’[17].

In the study area, sediments of Gondwana Supergroup occur in broad depression within Archaean metamorphites that are exposed both on the eastern (not shown in Figure 1) and western end of the basin (Figure 1). On the southern tip the Lower Gondwana sediments rest over the Sullawai quartzites with unconformable relationship[18] (shown in Figure 1). Towards north, the basaltic flows of the Deccan Trap cover the Gondwana rocks.

The Gondwana Supergroup of rocks in the study area is represented by Talchir, Barakar and the Kamthi formations (Table 1). The Talchir Formation in the area comprises older unstratified deposits (boulder beds) and younger stratified deposits. The unstratified deposits represent the poorly sorted, laterally discontinuous bodies, which vary in thickness from 0.5 to 2.0 m. These discontinuous bodies are yellowish-brown to greyish-brown, fine-grained sandstones to siltstones in which pebbles and boulders are unevenly dispersed. The clasts of feldspathic gneisses and mica schists are noticed from these matrix-supported unstratified deposits. Such unstratified deposits gradually pass upward into yellowish-brown, fine to coarse-grained sandstones. These sandstones are poorly sorted, show wide lateral continuity and vary in thickness from 0.2 to 2.5 m. Sandstones exhibit horizontal laminations, obscure ripple laminations as well as scour and fill structures. The very thin veneer of clay (1–2.5 mm thickness), is identified as varves. At places, siltstones showing ripple laminations also occur alternating with sandstones.

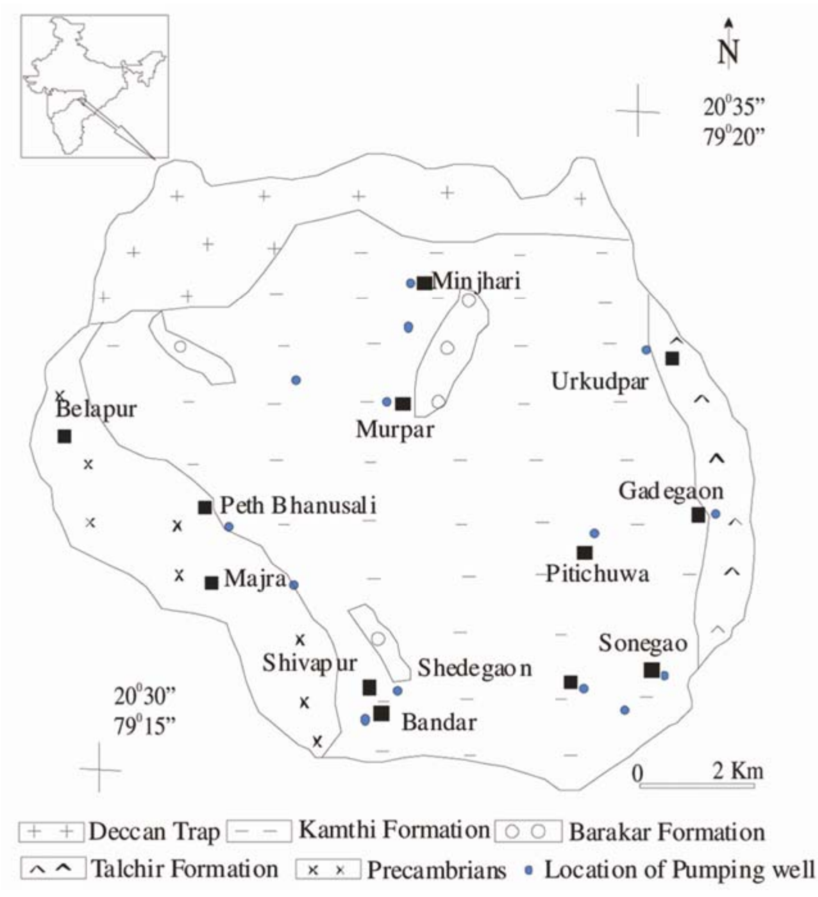

Figure 1. Location and geological map of the study area showing watershed WGAMG’0 and dugwells for the pumping test.

Table 1. Stratigraphy of the study area

Age	Group/formation	Lithology
Upon Cretaceous to lower. Eocene	Deccan Trap	Basalts
Cretaceous	Lameta	Limestone, cherts and silicified sandstones
- Unconformity - - - - - - - - - - - - - - -		
Uppper Permian	Kamthi	Sandstones, claystones/clay
- Unconformity - - - - - - - - - - - - - - -		
Lower Permian	Barakar	Fine- to coarse-grained sandstones. Shales and coal seams
Upper carboniferous	Talchir	Fine-grained sandstones, shales
- Unconformity - - - - - - - - - - - - - - -		
Proterozoic	Sullavai	Quartzose sandstones
- Unconformity - - - - - - - - - - - - - - -		
Archaean		Metamorphites

Table 2. Groundwater resource and components of groundwater recharge in the watershed area

Component	Details
Total watershed area	10,981 ha
Type of area	Non-command
Area suitable for groundwater recharge	10981 ha
Total annual groundwater recharge	1500.66 ham
Natural discharge	75.48 ham
Net groundwater availability	1434.18 ham
Gross draft	82.70 ham
Stage of development	5.77%
Recharge from rainfall	1481.03 ham
Recharge from groundwater irrigation	16.65 ham
Recharge from conservation structures	3.00 ham
Average pre-monsoon groundwater level	7.66 m bgl
Average post-monsoon groundwater level	2.91 m bgl
Average fluctuation	4.75 m
Pre-monsoon water table trend	Rising
Post-monsoon water table trend	Rising
Category of watershed	Safe

Source: Ref. 17.

The Barakar Formation is composed of the low-angle stratified sedimentary partings and coal seams. Based on predominant rock types with in-built primary sedimentary structures, three lithofacies of the Barakar Formation are identified: (i) large-scale trough cross-stratified sandstones, (ii) ripple laminated sandstones, and (iii) carbonaceous shale. In general, the cosets of large-scale troughs from large-scale trough cross-stratified sandstone facies are about 2.5 m thick and can be traced in down current direction up to 3 m. These sets occurring both as singularly as well as 3–4 cosets exhibit sharp tangential contacts with lower bedding surfaces. Besides, ripple laminations are also seen in these rocks. In addition, stacking of 2–3 sandstone beds exhibits grain size variations resulting into fining upward sequences. It is also noticed that medium to coarse-grained sandstones are overlain by thin veneers of very fine-grained sediments. The fine- to medium-grained ripple laminated sandstones occur as thin beds on the top of large-scale trough cross-stratified sandstones. A few ferruginous bands are noted from these sandstones. Carbonaceous shale commonly occurs on the top of the ripple laminated sandstone facies.

In the Kamthi Formation, the sandstones predominate over clay–claystones and carbonaceous shale. These sandstones (1.0–4.0 m thick) are yellowish-brown to white, coarse to fine-grained and friable. Beds show fining upward sequences that start with very coarse to coarse-grained sandstone, followed by medium to fine-grained sandstone with very fine-grained sandstone, clay-claystones and shales. Based on predominant rock types with inherent primary sedimentary structures, four lithofacies of the Kamthi Formation have been identified: (i) large-scale trough cross-stratified sandstone, (ii) horizontal bedded sandstone, (iii) ripple laminated sandstone and (iv) variegated clay–claystones. The large-scale trough cross-stratified sandstone facies is represented by yellowish-brown to greyish-yellow, coarse-to-fine grained and cross-stratified sandstone beds.

The study area, falling within the watershed WGAMG′0, has been categorized to represent the Gondwana sedimentary groundwater province[19,20]. In the study area, Gondwana sandstones constitute the aquifers. These sandstones possess primary porosity and are highly permeable; thus they constitute the good aquifer characters. However, due to the presence of clayey horizons, located at places, the groundwater potential is lowered[21,22].

The study area of the watershed (WGAMG′0) is oval-shaped, covering 109.81 sq. km. The study area exhibits dendritic drainage pattern, composed of totally 93 drainages ranging from order I to IV. All the drainages flow towards the southeast tip of the watershed area. Table 2 summarizes the component-wise groundwater recharge for the WGAMG′0 watershed. The observation wells fixed in the entire watershed area have sandstone as an aquifer and vary in depth from 9 to more than 16 m (Tables 3 and 4). Generally the well diameter ranges from 2.0 to more than 3.5 m. Usually, in the pre-monsoon season most of the wells are dry, while the post-monsoon groundwater levels grade between 2.1 and 7.9 m bgl.

Fourteen pumping tests were carried out on observation wells from the study area for estimation of aquifer

Table 3. Details of observation wells from the study area

Well. no	Location	Latitude	Longitude	Type of well	Use	Aquifer
1	Peth Bhanusali	20°32′23″	79°16′16″	DW	Dr/Do	Sandstone
2	Majra	20°29′23″	79°17′08″	DW	Irrigation	Sandstone
3	Murpar 1	20°33′21″	79°16′10″	DW	Irrigation	Sandstone
4	Murpar 2	20°31′27″	79°16′00″	DW	Dr/Do	Sandstone
5	Shivapur	20°06′34″	79°17′32″	DW	Irrigation	Sandstone
6	Bandar	20°02′44″	79°16′22″	DW	Irrigation	Sandstone
7	Minjhari 1	20°32′14″	79°16′03″	DW	Irrigation	Sandstone
8	Minjhari 2	20°34′28″	79°16′09″	DW	Irrigation	Sandstone
9	Shedegaon 1	20°30′08″	79°19′29″	DW	Dr/Do	Sandstone
10	Shedegaon 2	20°30′44″	79°20′05″	DW	Irrigation	Sandstone
11	Sonegaon	20°30′38″	79°21′05″	DW	Irrigation	Sandstone
12	Pitichuwa	20°32′38″	79°19′54″	DW	Dr/Do	Sandstone
13	Gadgaon	20°32′46″	79°21′04″	DW	Irrigation	Sandstone
14	Urkudpar	20°33′52″	79°21′15″	DW	Irrigation	Sandstone

Dr/DO, Drinking/Domestic; DW, Dugwell.

Table 4. Pre- and post-monsoon water table record of WGAMG′0 watershed

Well no.	Depth range (mbgl)	Well diameter range (m)	Pre-monsoon SWL (m)		Post-monsoon SWL (m)		Average yield of wells (lph)
			Minimum	Maximum	Minimum	Maximum	
1	10.3	2.6	8.4	9.7	2.6	4.7	1652
2	15.1	2.4	14.1	Dry	4.1	5.7	2708
3	10.6	2.4	8.2	9.6	2.6	3.7	2034
4	15.5	2.8	14.5	Dry	6.2	7.8	2663
5	15.1	3.1	14.2	Dry	2.4	3.8	1658
6	16.9	2.6	14.3	Dry	6.6	7.6	1867
7	10.7	2.5	8.1	9.9	2.6	3.8	2231
8	12.1	3.5	9.7	11.9	2.3	3.9	1938
9	14.6	3.0	12.4	13.7	4.3	5.8	2554
10	15.4	2.5	14.1	Dry	6.1	7.7	2576
11	15.7	2.25	14.4	Dry	2.2	3.9	2017
12	9.9	3.0	8.1	11.6	2.1	3.9	3549
13	10.3	3.5	8.4	9.8	4.3	3.8	2834
14	9.8	3.0	8.3	Dry	2.2	3.9	1988

parameters. Pumping tests were carried out for the period ranging from 60 to 90 min, while the total recovery time extended from 90 to 110 min. These tests were carried out according to the standard procedure of the recovery method following Kruseman and de Ridder[11]. The data thus generated were analysed to determine aquifer parameters, namely transmissivity (T) and specific yield (S) of the shallow phreatic aquifer (Table 5). Representative sandstone samples were collected from the observation wells piercing the aquifers. The samples were subjected to petrographic study[23,24]. The grain-size data generated were processed to evaluate textural parameters[25], viz. graphic mean (Mz) and inclusive graphic standard deviation (σ_{I}).

The volume percentage analysis of 14 sandstone samples was carried out using ribbon-counting method (Table 6). These sandstones representing the aquifer rock were categorized as arenites[26] (eight samples) and wackes (six samples).

The framework components from the arenite rock types are quartz (av. 60.21%), mica (av. 2.46%), feldspar (av. 8.53%), rock fragments (av. 7.81%) and others (av. 1.73%). The monocrystalline quartz grains (av. 56.2%) dominate over the polycrystalline quartz grains (av. 4.19%). Among the monocrystalline quartz grains, the non-undulatory quartz grains (av. 52.46%) dominate over the undulatory quartz grains (av. 3.56%). Similarly, the framework components from the wacke rock types are quartz (av. 39.94%), mica (av. 4.37%), feldspar (av. 8.84%), rock fragments (av. 7.46%) and others (av. 1.05%). The monocrystalline quartz grains (av. 38.86%) from the wackes also dominate over the polycrystalline quartz grains (av. 1.08%). Likewise, among the monocrystalline quartz grains the non-undulatory quartz grains (av. 37.48%) dominate over the undulatory quartz grains (av. 1.38%).

The arenites are primarily composed of silicious and ferruginous cementing materials, which vary from 7.38%

Table 5. Particulars of pumping tests

Well no.	Pumping duration (min)	Draw down (m)	Recovery duration (min)	Residual drawdown (m)	Discharge (m^3/day)	Transmissivity (m^2/day)	Specific yield (%)	Rock type
1	80	3.7	110	0.52	998.64	104.85	23	Arenite
2	80	5.8	110	0.92	1947.47	450.42	35	Arenite
3	80	5.4	110	0.99	1913.67	412.72	29	Arenite
4	70	2.4	100	0.69	923.37	211.27	20	Arenite
5	90	3.5	180	2.1	139.69	58	10	Wacke
6	90	3.6	100	0.71	473.18	61.17	14	Wacke
7	60	2.4	100	0.42	840.19	158.29	24	Arenite
8	70	2.5	110	0.44	830.57	160.71	22	Arenite
9	80	2.7	100	0.70	412.71	75.36	13	Wacke
10	70	2.6	110	0.76	425	146.43	16	Wacke
11	70	2.7	100	0.70	485	165.59	17	Wacke
12	90	2.7	90	0.69	421.73	73.16	13	Wacke
13	60	2.3	100	0.68	935.55	209.07	21	Arenite
14	70	3.6	110	0.51	1027.74	102.28	27	Arenite

Table 6. Textural details of sandstones

Specimen from well no.	Monocrystalline quartz			Polycrystalline quartz	Total quartz	Cement	Matrix	Mica	Feldspars	Rock fragments	Others	M_z (ϕ)	σ_I (ϕ)
	Non-undulose	Undulose	Total										
1	69.55	2.77	72.32	2.76	75.08	7.38	8.33	1.93	7.38	5.97	1.31	1.38	0.94
2	60.97	3.71	64.68	3.89	68.57	8.65	9.31	3.26	8.65	7.86	2.35	1.56	0.98
3	68.51	3.19	71.7	2.86	74.56	7.62	8.54	1.86	7.62	6.14	1.28	1.29	0.76
4	55.04	2.94	57.98	6.12	64.1	8.25	14.84	1.52	8.25	10.34	0.95	1.98	1.01
5	36.42	1.25	37.67	1.77	39.44	5.62	36.11	5.43	5.62	11.28	2.12	0.12	1.60
6	45.66	1.36	47.02	0.62	47.64	10.2	30.3	4.1	10.2	6.85	0.91	0.68	1.32
7	58.73	4.12	62.85	4.08	66.93	9.42	10.36	3.6	9.42	7.12	2.57	1.79	0.93
8	57.42	5.51	62.93	5.88	68.81	9.23	10.35	3.3	9.23	6.66	1.65	1.69	0.95
9	52.63	1.93	54.56	2.13	56.69	9.87	22.05	4.01	9.87	6.74	0.64	0.44	1.02
10	46.27	1.24	47.51	0.76	48.27	8.39	31.01	4.82	8.39	7.01	0.5	0.86	1.34
11	40.26	0.86	41.12	1.34	42.46	5.38	35.07	4.96	5.38	10.28	1.85	0.92	1.27
12	46.79	1.52	48.31	0.53	48.84	10.37	29.06	3.96	10.37	6.41	1.36	0.77	1.26
13	56.23	2.55	58.78	5.87	64.65	8.13	13.76	1.67	8.13	10.19	1.6	1.34	0.98
14	61.45	3.7	65.15	2.06	67.21	9.57	10.34	2.56	9.57	8.17	2.15	1.23	0.72

to 9.57%. The wackes are also composed of silicious and ferruginous cementing materials, which vary from 5.38% to 10.37%. The matrix in the arenites ranges from 8.34% to 14.84%, and in wackes it ranges from 22.05% to 35.07%.

The arenites are medium-grained (Mz = 1.23 to 1.98ϕ) and moderately sorted (σ_I = 0.72 to 0.91ϕ). The wackes are coarse-grained (Mz = 0.12 to 0.92ϕ) and poorly sorted (σ_I = 1.02 to 1.60ϕ).

It is observed that quartz grains from arenites are subrounded (0.26–0.38) and subequant (0.69–0.71) to subelongate (0.64–0.66). However, the quartz grains from wackes are subangular (0.21–0.25) to subrounded (0.26–0.28), and subelongate (0.64–0.0.63) to elongate (0.60–0.63).

The pumping tests were carried out in dugwells from the study area for estimation of aquifer parameters, namely transmissivity and specific yield (storativity; Table 5). The transmissivity values for arenites range from 102.28 to 450.42 m^2/day, and for wackes from 58 to 165.59 m^2/day. The values of specific yield for arenites range from 20% to 35% and for wackes from 10% to 17%. The average discharge from the arenite aquifer is 1177.15 m^3/day, whereas for wacke aquifer it is 392.89 m^3/day.

The petrographic data along with textural details generated for arenite as well as wacke sandstones representing the aquifers include computation of framework constituents along with calculation of percentage of matrix, as well as roundness and sphericity measurement of quartz grains. Though the arenites as well as wackes are primarily composed of silicious and ferruginous cementing materials, the cementing material from the former is less (av. 8.53%) than that from the latter (av. 10.37%). The matrix percentage is more in wackes (av. 29.55%) and remarkably low in arenites (av. 10.73%).

The evaluated values of transmissivity as well as specific yield are ascribed to the texture of the rocks. The high values of transmissivity (av. 226.20 m^2/day) and specific yield (av. 25.13%) in arenite aquifers correspond to higher percentage of detrital grains, lesser amount of matrix and moderate sorting of the grains. It is observed that quartz grains from arenites are subrounded and subequant to subelongate. Conversely, the lower percentage of detrital grains, higher amount of matrix, poor sorting of the grains correspond to low values of transmissivity (av. 96.62 m^2/day) as well as specific yield (av. 13.83%) in wacke aquifer. The quartz grains from wackes are subangular to subrounded and subelongate to elongate.

The individual particles of the geological formation are not entirely spherical and thus during their deposition by the geological agency, these particles tend to settle down on their flat sides[11]. Thus, groundwater movement in the horizontal direction is greater than that in the vertical direction, causing anisotropy. Thus, from the present study it can be postulated that, since the quartz grains from wackes are subangular to subrounded and subelongate to elongate, groundwater would not move with ease as it moves through arenites, where the quartz grains are subrounded and subequant to subelongate. In addition, the clay minerals also obliterate the inter-connection of voids by means of their natural tendency to settle down with their nearly flat surface parallel to the bounding surfaces of sedimentary rocks. Due to such controlled cessation of inter-connected paths, the vertical movement of groundwater becomes sluggish. When the petrographic and textural parameters of the aquifers are correlated, as carried out in the present study, it can be propounded that the percentage of detrital grains, their roundness and sphericity, and matrix are the prime factors that govern the movement of groundwater through the particular aquifers.

The schematic models presented[27] for arenite as well as wacke (Figure 2) are also supported by the aforementioned discussions. These models also show that transmissivity and specific yield (storativity) are functions of movement of groundwater in the vertical as well as horizontal direction.

Thus the present study has a bearing on the laboratory findings regarding petrographic characters and aquifer characteristics. The results of the present study indicate the following:

(i) The high values of transmissivity and specific yield in arenite aquifers correspond to the higher percentage of detrital grains, lesser amount of matrix and moderate sorting of the grains.

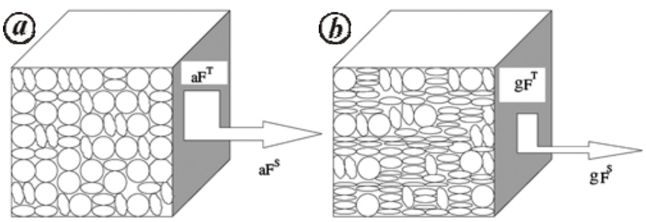

Figure 2. Schematic models revealing groundwater movement through (***a***) arenite and (***b***) wacke. aF^T and aF^S are the representative functions of transmissivity and specific yield of arenite respectively. gF^T and gF^S are the representative functions of transmissivity and specific yield of wacke respectively.

(ii) The lower percentage of detrital grains, higher amount of matrix and poor sorting of the grains exhibit low values of transmissivity as well as specific yield in wacke aquifers.

(iii) Groundwater movement in the horizontal direction is greater than that in the vertical direction, causing anisotropy in both types of aquifers. Since the quartz grains from wackes are subangular to subrounded and subelongate to elongate, groundwater cannot move with ease as it moves through arenites, where the quartz grains are subrounded as well as subequant to subelongate.

(iv) In addition, the clay minerals from the matrix also obliterate the inter-connection of voids by means of their natural tendency to settle down with their nearly flat surface parallel to bounding surfaces of sedimentary rocks. Due to such controlled cessation of inter-connected paths, the vertical movement of groundwater becomes sluggish.

(v) When the petrographic and textural parameters of the aquifers are correlated, as carried out in the present study, it can be propounded that the percentage of detrital grains, their roundness and sphericity, and matrix are the prime factors that govern the movement of groundwater through the sedimentary aquifers.

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Wind-induced response of half-storey outrigger brace system in tall buildings

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In all previous studies, the outrigger arms are symmetric with respect to the centre line of the core. Hence, each outrigger involves two arms at the same level which usually occupy one, two or three stories. In this communication, the innovative idea is to implement the outrigger arms asymmetrically. One main purpose of this study was to investigate the feasibility study of four half-storey outriggers system instead of the corresponding two-storey outrigger system. To study the effects of the newly defined configurations on the global performance of tall buildings, some 30-, 45- and 60-storey two-dimensional steel frames with braced core systems at centre have been analysed and designed under gravity and wind load without outriggers. Later, the outrigger trusses were added in different arrangements at the optimum locations. The results show that the new idea will improve the system efficiency.

Keywords: Half-storey-outrigger, inter-storey drift, steel frame, wind load.

IN tall buildings, there are many points and design criteria which should be considered by structural engineers. The most important design criteria may be strength, serviceability, stability and human comfort. The goal of the designer is to attain convenient schemes, to satisfy these criteria, and achieve the lowest weight per unit area for the structure[1]. Mendis *et al.*[2] recommend that a limit of $H/500$ should be used for the maximum inter-storey drift (IDR) to assure serviceability under wind load (H is the total height of the building). This value is consistent with a recommendation given in the National Building Code of Canada and survey results which indicated that designers of steel-framed buildings in USA use a drift limit ranging from $H/600$ to $H/200$.

While 35 to 40-storey buildings can conventionally rely solely on shear wall and braced core systems, the resistance of these systems to lateral displacement decreases approximately with the cube of building height. Thus, braced core systems become highly inefficient for taller buildings[3,4]. The outrigger system is capable of providing up to 25–30% additional stiffness compared to a system without such trusses[5]. Taranath[6] studied the optimum location of a single outrigger added to the structural system with the aim of reducing the building roof displacement under the wind load and presented an

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